The University of Alberta

The Transfer of Technology from an Ergonomic Office Chair to a New Indoor Wheelchair Design

by

Franz Roland Kurzitza, *BFA*

A technical report in support of a project
submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of
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in

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Abstract

This report documents the design of a new wheelchair, using the transfer of technology from an ergonomic office chair to address the needs of long-term wheelchair users. The design process is documented from the concept to the final prototype and initial testing. The report also summarizes research and the Aeron™ chair technology.

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Professor
Industrial Design
University of Alberta

Lili Liu, *Ph.D.*
Associate Professor
Occupational Therapy
University of Alberta

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* All figures illustrated by F. Roland Kurzitza

Introduction

Industrial design ideas frequently result from the combination of seemingly unrelated things. This thesis project results from this kind of combination.

In the fall of 1996 I attended a design lecture at the University of Alberta, delivered by Dr. Norman Ball, from the University of Waterloo. The lecture, "Reading Industrial Design" focused attention on the intent of the designer and how users perceive products. The product subject of Dr. Ball's lecture was an office chair, known as the Aeron™ chair, manufactured by the Herman Miller company of Zeeland, Michigan, USA.

Ergonomically designed chairs with adjustable features are widely available. The adjustability of the seat, armrest heights, and seat and back angles are now standard features in all chairs that are described as "ergonomic". The Aeron™ chair, however, has two features that are unique, namely the Kinemat™ tilt system, and the Pellicle™ material used for the seat and back support.

During the fall of 1996, at about the same time as Dr. Ball's lecture, my wife, an RN at the Misericordia Hospital, described problems experienced by invalid patients from sitting for prolonged periods in wheelchairs. The most frequent of these problems was the outbreak of sores and perforations of the skin, which then require expensive surgery to correct. The ergonomic features of the Aeron™ chair, with its Kinemat™ tilt system and specialized Pellicle™ fabric led me to consider a new concept in wheelchair design which could substantially reduce this problem.

This "wheelchair" thesis project results from combining the ergonomic features of the Aeron™ chair with the need to address those recurring problems faced by patients in long term care facilities, whose infirmity and disability require them to sit for long periods.

™ Aeron, Kinemat, and Pellicle are registered trade marks of Herman Miller Inc., Zeeland, Michigan, U.S.A.

Review: of the literature

Prior to 1970, wheelchair seating "improvements" consisted primarily of cushions arbitrarily selected by medical or rehabilitation teams.[1] Various approaches to seating have been described within biomedical, ergonomic, neurodevelopmental, functional, and pressure-related contexts.[2] Before the 1980s, wheelchair seating was categorized in one of two ways: seating for positioning and seating for pressure relief. Seating for positioning evolved specifically for children with cerebral palsy whereas seating for pressure relief was reserved for individuals with spinal cord injuries.[3] People confined to nursing homes and those who had had a stroke were largely ignored with regard to their seating needs.[4] "The evolution of the wheelchair of the 1990s has created an expensive and often confusing market. Rarely are therapists who measure for and recommend wheelchairs completely knowledgeable about the many variations in wheelchair bases and the numerous options."[5]

Seating solutions are still seen as add-on cushions and seating systems to the tubular framed wheelchair. Cooper gives a very good overview of the various classes of manual wheelchairs and all of them use frame designs that rely on various tubular structures with seats that span the frame with a variety of sling fabrics or rigidly supported foam.[6] "A population whose wheeled mobility and seating needs are largely ignored is elderly."[7] The elderly in nursing homes often sit in wheelchairs on cushions that are uncomfortable and in positions that "inhibit rather than enhance function."[8] Monga and Zimmermann report a study where 80% of the elderly population experienced at least one seating and mobility problem, of which 34% were considered to be servere.[9] Problem areas included discomfort, hindered or lack of independent mobility, sliding, leaning, impeded transfers, and occurrence of pressure sores. Two major reasons were cited as problems: (1) the technology was developed for younger physically impaired populations and therefore may not be suited for the elderly and (2) the technology is unavailable because of cost, lack of information, and lack of service facilities.[10]

Horsley states that pressure sores or decubitus ulcers are a nursing problem not a design problem related to furniture such as beds and wheelchair seating. The problem of decubitus ulceration appears to be a particularly important area of nursing research as "it is the nurse who holds prime responsibility for its prevention."[11]

Despite the fact that many innovations are occurring in the outdoor wheelchair market, the "indoor" wheelchair with the caster configuration in the rear has been largely ignored. Many wheelchair publications do not mention indoor wheelchairs and even Cooper dismisses them as "less stable".[12] The elderly spend most of their time indoors, and have special requirements of wheelchairs which have not been met. This clearly indicates a need for the redesign of the indoor wheelchair.

Research Summary

Brief History

The wheelchairs' origin is unknown, however there is speculation that the chair originated in ancient Egypt It is known that wheeled carts existed in ancient Sumeria as early as 3500 BC.[13] The chair and the wheel were not formally connected to carry the sick or infirm until approximately the fifth century AD in China.[14] (*Figure 1*) Normally these people were carried by family or servants in hammocks over rough roads.[15]

Figure 1. A Chinese sarcophagus, dated about 525 AD, depicts a man in a three-wheeled cart

Another Chinese invention — the wheelbarrow, became a popular means of moving the sick and the dead in the Middle ages in Europe. By the 15th. century small wheels were being attached to heavily padded arm chairs and called "comfort chairs" or "invalid chairs," and by the end of the 17th. century self-propelled wheelchairs fitted with hand cranks for paraplegics, designed by Johann Hautsch of Nuremberg, were in limited use. Wheeled chairs were mainly used indoors and outdoor excursions still relied on the strong backs of family members and servants using slings, litters, or sedan chairs.[16]

A wheeled chair invented by John Dawson in 1798 for the spas in Bath, England became popular in the 19th. century. (*Figure 2*) This chair used the buggy technology of the day and had two large wheels at the back and one smaller front wheel that the user could steer. This chair needed an attendant to push it. There seem to be no reports of wheelchairs in North America until the American Civil War, when wooden chairs with wooden wheels were used. In 1932, Herbert A. Everest, an injured mining engineer, and Harry C. Jennings, a mechanical engineer, designed and manufactured a folding wheelchair that is the forerunner for today's basic or standard chair. (*Figure 3*) Each manufacturer today uses similar technology and design for the basic chair, which seems to be a suitable compromise between, stability, maneuverability, and portability.[17]

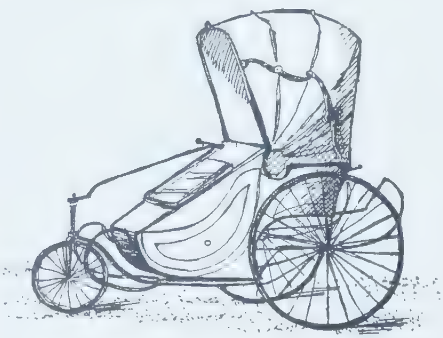

Figure 2. A wheeled chair invented by John Dawson in 1798 in Bath, England.

Current Wheelchairs

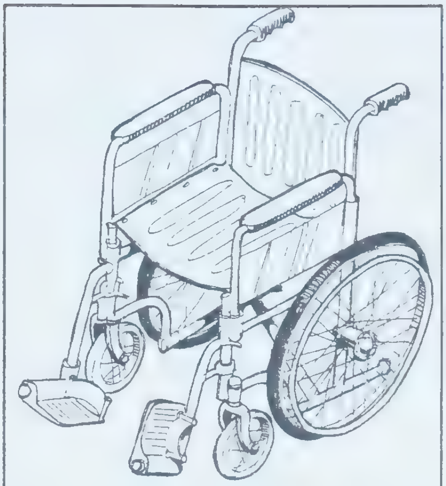

Figure 3. The standard folding wheelchair.

People who are relegated to the long term use of a wheelchair are susceptible to numerous potential problems. One's medical history and condition, motor and sensory function, propensity for skin breakdown, orthopedic problems, bowel and bladder function, as well as the method of transfer in and out of the chair both effect and are affected by the seat surface or the type of cushion used.

People who lack sensation or who have trouble shifting weight and changing positions are at risk for skin breakdown. Decubitus ulcers or pressure sores are the result of excessive or prolonged pressure while sitting in a chair. However, they can also occur because of skin shear from sliding; heat and moisture buildup from incontinence or perspiration; and repeated trauma during transfers. Poor nutrition, poor circulation, low muscle tone or bulk, age, and poor posture all make a person more susceptible to skin breakdown. A well designed wheelchair should decrease pressure over bony prominences, maintain better postural alignment, dissipate heat and moisture, and ease transfers.[18]

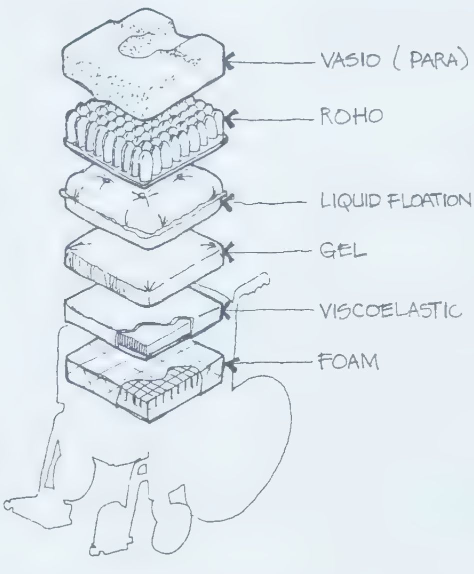

Figure 4. Various seat cushions used.

It is generally acknowledged that the standard sling seat upholstery on most wheelchairs provides a poor base of support for the user.[19] Numerous attempts have been made to address this problem by adding a variety of cushioning materials. (*Figure 4*) The size, angle and shape of the sitting surface and the composition of the materials used for cushioning all influence how well a seat works. Specific medical problems and their attention are outside the scope of this project. However, it was apparent to me that many of the problems described above are either created or exacerbated by standard wheelchairs, and could be alleviated or lessened by implementing the technology of the Aeron™ chair in a wheelchair redesign.

Aeron™ Chair Technology

Herman Miller's Pellicle™ material is the technology that I feel would most eliminate or reduce skin problems. Pellicle™ means thin skin, or membrane. In talking with Bill Dowell, Herman Miller's research program manager and ergonomist, I discovered that several different pellicle materials have been tested. The design team discovered that an elastic material that stretched in every direction did not give the desired pressure map during testing. Their final design for the Pellicle™ material stretches only in one direction, horizontally on the back and side to side on the seat. Continuous testing with the pressure mapping device showed that in order to obtain the optimum pressure map, the Pellicle™ material had to be fastened to the frame using different tensions in specific areas. For example; the lumbar area of the back must be sprung with less tension than the upper part to achieve the correct results.[20]

The 'Pellicle™' material used in the Aeron™ chair is unique because it replaces both foam and fabric in the seating system. It is a mesh or breathable membrane of three synthetic polymers, one of which is Hytrel. Hytrel is used by General Motors in a limited way in car seats, impregnated in the foam Engineers refer to Hytrel as "topographically neutral", which means it returns to its original shape after being stretched. The Pellicle™ material has been engineered to both give where needed and support without creating 'hot spots' of either temperature or pressure. [21]

The seat and back of the Aeron™ chair were designed to fit from the 1st percentile female to the 99th percentile male. There is approximately 17 inches in height and 140 pounds in weight difference between these two extremes. In order to fit this wide range of the population the Pellicle™ material is stretched proportionately over three sizes of frames.

> "Adjustments for seat height, lumbar height and depth, arm height and width, and tilt tension enable the sitter to fine-tune chair dimensions and performance to personal preferences. Finally the unique stretch of the resilient Pellicle™ material of the seat and backrest automatically conforms to individual body contours."[22]

The Pellicle™ material has other attributes that make it desirable for wheelchair use. First, it allows the body to maintain thermal equilibrium with the environment. Secondly, the porous nature of the Pellicle™ material allows humidity to disperse. Air flow to the areas of the body in contact with the Pellicle™ are almost equal to the exposed parts of the body. This results in dryer skin with little or no heat buildup, thereby facilitating comfort. The surface of the Pellicle™ material does not offer much friction yet the give of the material holds the sitter firmly in place. These are the very qualities which are sought after by wheelchair specialists to improve seat comfort and reduce skin damage caused by skin shear, moisture, and pressure.[23]

The designers of the Aeron™ chair have studied, at length, how the body moves from an upright seated position to a reclining seated position and have patented a system they call the "Kinemat™ tilt."

> "In an upright position, the self-shaping ischial target in the seat pan and the forward pressure on the iliac crest created by the contour of the backrest and the adjustable lumbar pad create a pocket to hold the pelvis at a slight forward tilt to enhance lordosis. [Lordosis means the forward curvature of the lower spine.]
>
> As the chair reclines, the feet remain flat on the floor as the lower leg pivots around a stationary ankle joint. The backrest drops about the hip pivot point, maintaining the same point of contact between the backrest and the iliac crest throughout the range of motion.
>
> The seat pan drops about a pivot point in the ankle joint in a synchronous relationship to the backrest to maintain the pelvic pocket and preclude lumbar shear (in which the chair's lumbar support moves away from the sitter's lumbar region) in all tilt angle positions. Armrests move with the backrest to support the arms as the drop back in their natural rotation at the shoulder joint."[24]

I see this reclining action as also being very desirable in wheelchairs. This would allow the sitter to semi-recline in a more relaxed sitting position, without getting out of the wheelchair, and to let the back distribute some of the body weight lessening pressure on one's bottom. It also reduces direct vertical lumbar load.

Target Group

Most nursing home residents are issued a facility wheelchair upon admission. Typically, these chairs have sling seating with little or no adjustment features. They were designed for limited transportation, and for the occupant to be pushed rather than to be self-propelled. They were not designed for long-term sitting needs.

Unfortunately, however, nursing home residents often end up sitting in these chairs all day long. As a result, they experience discomfort and are frequently at risk of sliding out of the wheelchairs. These problems are typically resolved by continual repositioning by facility staff. Some nursing home staff members use wedge cushions, lap trays, arm bolsters or elevating leg rests to prevent sliding. This equipment often doesn't work or complicates the problem making it more difficult for residents to self-mobilize and to transfer out of their wheelchairs. [25]

Many nursing home residents have very poor hamstring length and can't reach standard footrests. As a result, it is important to evaluate the hamstring length as it relates to sitting before positioning the resident with front riggings. In an institutional setting, removing footrests, if they are not needed, can allow residents to use their feet to self-propel or to reposition their feet during the day. Removing footrests can also reduce lower-extremity skin tears and reduce the risk of falls from tripping over the front riggings.

Pelvic migration can also be caused by improper seat-to-floor height. Some residents scoot out to the edge of the wheelchair seat in order to reach the floor for foot propulsion. Residents sometimes migrate to the edge of the wheelchair, pressing their trunk into the back upholstery to foot propel. This method not only promotes poor

sitting posture, it also translates into poor upright standing posture. My wheelchair design would properly fit a larger percentage of the population and would be an advance in the comfort and well-being of people in an institutional environment.

The esthetics of a chair contributes to the self image of the person using it. The institutional chair doesn't have to be devoid of style. Everyone needs to maintain self respect, including the elderly and infirmed. The design of this wheelchair is not a styling exercise. The esthetics of the wheelchair resulted from my attempt to focus on the intended users' needs — both physically and psychologically, while complying with the 'visual language' of the Aeron™ chair.

Most standard wheelchairs fold for storage and ease of transportation which compromises the ability of the seat to be designed for optimal comfort. I have observed that many wheelchairs in hospitals and nursing homes are left open when not in use. Also, most long term users travel while seated in their wheelchairs in vehicles designed for disabled transport. Therefore, I felt folding need not be addressed in this design.

Concept Development

With a model, I was able to understand some of the fundamental problems of structure, geometry, and esthetics relating to the chair. Producing a quarter scale working replica of the Aeron™ chair using research information published by Herman Miller,[26] I began to understand the language of its sophisticated curvilinear forms. This understanding was pivotal to my undercarriage design. For further background see appendix B.

Testing Mule

Before I could design the undercarriage I needed to determine appropriate dimensions for the wheel base. I built a full-scale *testing mule* from old standard wheelchair frames which allowed me to adjust both wheel base and chair positioning. (*Figure 5*) Using this method I found the minimum foot print while maintaining maximum chair stability. This trial and error approach allowed me to learn about the various forces imposed on the structure. The detailed engineering required for the final undercarriage design is outside of the scope of this project.

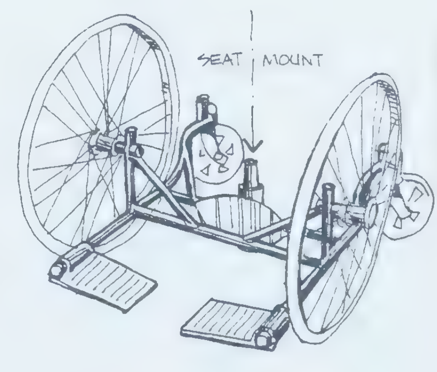

Figure 5. Testing mule

There are five main points that I was able to take from the testing mule and apply to my first prototype. They are:

a. In order for the chair to semi-recline, the large wheels must be at the front. This is dictated by the fact that the arms are attached to the seat back and therefore recline in unison with the back. If the seat was oriented like most wheelchairs with the casters in front, the armrests would bump into the large wheels and severely restrict the reclining action. With the casters at the back, rearward stability is excellent, even at full recline.

b. Vertical height adjustment was an advantage and must be incorporated into further prototypes.

c. The option which allowed a five degree forward tilt of the seat pan in the Aeron™ chair did not prove practical for wheelchair use.

d. The armrests are adjustable both vertically and horizontally. The vertical adjustability was useful. The seventeen degrees outward pivot of the arms is designed to facilitate using a mouse while keyboarding in an office setting. This proved to be a drawback in a wheelchair. Most people who exit the chair use the armrests for support when initiating the standing motion. The sudden outward motion of the armrest, when force was applied in its neutral position, was destabilizing and problematic for the user; so I disabled this movement by adding an internal stop to the pivot. The fifteen degrees inward pivot was very important to this wheelchair. It moved the arms in and out of the way so it is easier to grasp the front wheel push rings.

e. I initially located each footrest at the front perimeter, allowing the knees to be at approximately a ninety degree angle. This proved very comfortable but people consistently forgot to remove their feet from the rests and stood up almost catapulting themselves out of the chair. The footrest positioning needed more work.

Prototyping

Prototype I

At this point I produced full-scale orthographic drawings, and made some shop drawings to facilitate frame construction for my prototype using 3/4" x 1 1/2" and 3/4" x 3" mild steel tubing. This provided me with reasonable structural strength at a low cost and I was able to do all the cutting, welding and assembly in-house.

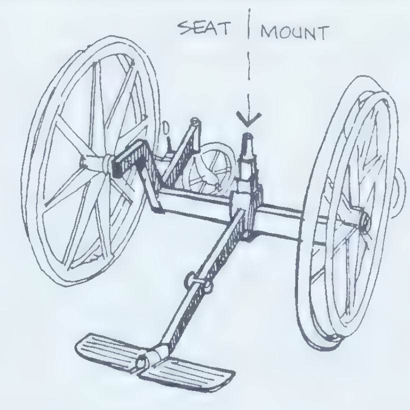

Figure 6. Prototype I, undercarriage.

My quarter scale model allowed me to *step back*, in order to see the bigger picture — functionally and esthetically. I would need a wheel with as few spokes as possible because wheelchair users and attendants need access to seating controls located under the seat pan.

An appropriate solution to the footrest location was to place both footrests together on a centrally mounted arm made of tubular steel. By placing the feet somewhat forward. users were no longer inclined to forget to take their feet off the rests when exiting the chair; effectively solving the catapulting problem. Also. having both footrests together solves a problem expressed by some caregivers, that some wheelchair users' feet accidentally slide off the rests into the middle.

I used standard wheelchair brakes that apply pressure to the outside of the rubber wheel which I affixed onto the lower wheel strut to the rear of the large front wheels. This location could be reached by the wheelchair user or a care giver.

A variety of casters were tested on this prototype. The larger the diameter the wheel the easier it is for that wheel to negotiate over small obstacles. Since the wheelchair was being designed for indoor use, typical obstacles would be small toys, pens or pencils, lamp cords, carpets edges and thresholds. I found that the 6" diameter caster turns with slightly less effort than the 8" diameter caster and performs just as well maneuvering over small objects. Therefore, I chose the 6" diameter caster for its better maneuverability, and this size also works better visually with the overall design of the wheelchair.

Synopsis

This wheelchair allows the user to semi-recline and remain very stable. It is easy to maneuver and negotiate through an interior environment. It seems easier to roll up to regular tables which have legs at the corners. The wheelchair got good reviews from everyone who sat in it. The turning radius is within its own footprint and it easily fits through a standard 2'-6" door.

When coasting in a straight line, such as going down ramps, the back end of the wheelchair tended to swing out or around. This was because the casters were located at the back. However, as discussed earlier, there were good reasons for putting the casters in the back. In fact they had to be there and the tracking problem would simply have to be addressed. I realized that the tracking of any vehicle with free wheeling casters will be influenced by the slope of the terrain. When one is negotiating across a side slope, front casters tend to turn the wheelchair down the slope; rear casters tend to turn the wheelchair up the slope. Devices have limitations and no matter what the designer does, all wheelchair users must cope with the wheelchairs tendency to turn on side slopes. The chair's tracking ability on level surfaces was improved by modifying: camber, wheel base and track width. Through experimentation, I decided to use a negative camber of 1 1/2 degrees. I also lengthened the wheel base an inch

to a total of 18", and narrowed the rear track to 16". Another weakness of the indoor chair wheel configuration is its inability to climb a step or curb higher than 3". This limitation is acceptable as the chair is intended for interior use only.

I discovered it was impractical to incorporate the pneumatic height adjustment into my design. The torsion forces on the point of the chair's anchorage are so formidable, that the seat always pivoted when the height was adjusted. This solution was potentially hazardous and might frighten users. Therefore, I have temporarily abandoned the vertical seat adjustment. In an institutional setting where patients have a dedicated chair, height could be adjusted to suit the individual. Multi-user chairs would have to be set at a pre-determined optimum for the user group. There is a possible design solution which would allow height adjustment without rotation. However, it was not pursued because it would cost about $1,000.00 to test.

I also found that my brake location was too low for most people. This fact requires re-thinking the design of the parking brake and/or the undercarriage geometry. The first prototype was too angular, stylistically, and required using a visual language more compatible with the Aeron™ chair.

Prototype II

As a result of the discoveries made on the first prototype I began working on the form and function of the undercarriage. I relocated the brakes higher on the frame for easier access. Reacting to the straight lines in the first prototype and guided by the visual language of the Aeron™ chair, I took tentative steps toward rationalizing the esthetics of my design. I attempted to make this undercarriage appear lighter by introducing curves. The forms and structure appropriate to my emerging design, at this time, could only be realized in sand cast aluminum. This low tech solution could be accomplished locally at a reasonable cost. Aluminum could also take a warm-black matte crackle finish which approximates the finish of the Aeron™ chair. Many off-the-shelf parts including standard brakes, casters, wheels, tires, push rings, bearings and handle grips were used to make the working prototype cost effective.

Prototype III

Most of my concerns regarding ergonomics, maneuverability, stability and basic engineering were resolved through 'bench' testing prototypes I and II. See appendix A for testing methodology.

Undercarriage

The final undercarriage design complies with the 'personality' of the Aeron™ chair. I used a similar visual language to create my own forms which are separate but complimentary to the chair. I also used the same

friction-fit tapered spike mount that the Aeron™ chair uses for its office base, so that the chair will fit, without modification, to my undercarriage.

After producing many iterations in Styrofoam, I designed the undercarriage with two longitudinal members at the perimeter that hold the wheels and casters, and one cross-member with a detachable footrest assembly. After developing an appropriate structure, I took a mock-up to American Aluminum and Brass, a commercial foundry, and sought their advice which helped me produce the wooden patterns suitable for sand-casting. The resultant castings were then machined, welded, finished and painted. (*Figure 7*)

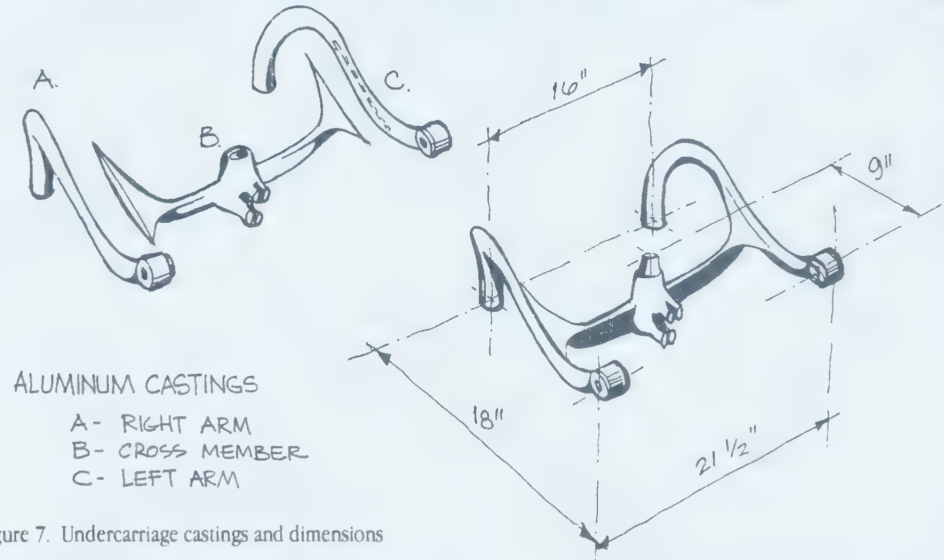

Figure 7. Undercarriage castings and dimensions

Centre mounted footrest

The removable footrest presented a significant design problem. The footrest and the seat pan are the only horizontal planes in the chair and both must bear weight. The footrest should be aesthetically pleasing as well as functional and structurally sound. The design solution was to have the footrest mimic the form of the seat pan. The individual footrests were drawn in from the conventional edge mounting and put on either side of a centrally mounted removable footrest support. The left and right footrest flip up to make it easier to get in and out of the chair. The whole footrest assembly may be detached simply and quickly by pushing a lock button. (*Figure 8*)

The footrest in its present form has several major design and engineering problems. Both right and left footrest wings have not stood up to even modest bench testing. The welds have broken several times. I seriously under-estimated the strength and capacity of the hinge. Although the current configuration looks good, it needs to be strengthened to withstand the forces that will be applied during use. This refinement could come through the use of other materials coupled with reengineering and design.

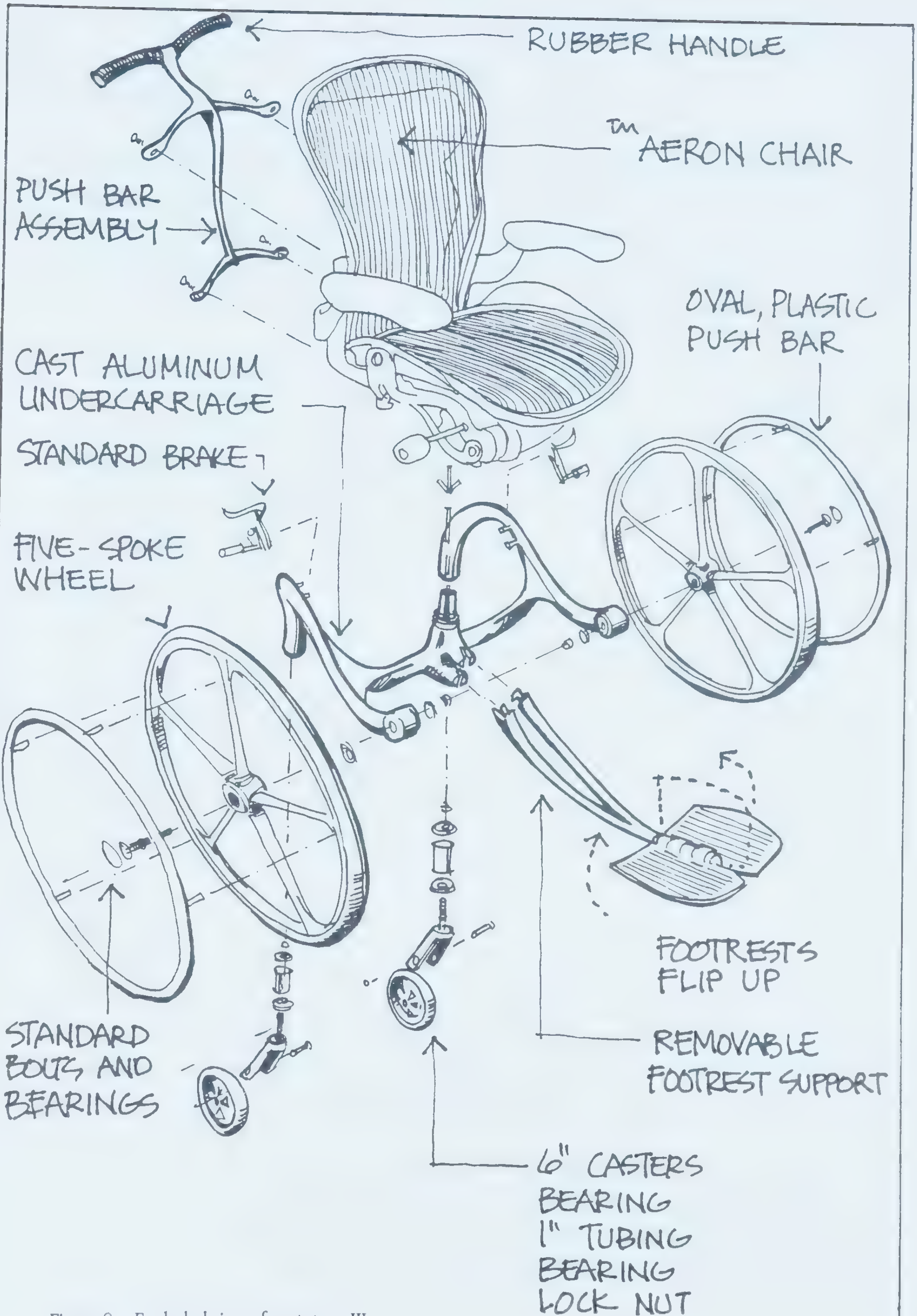

Figure 8. Exploded view of prototype III

Push handle

Most wheelchair push handles are poorly oriented for the attendant. The handle grips are usually hard plastic and they protrude straight back, forcing the hands into an uncomfortable position. They look clinical and communicate the need for a caregiver. To improve both the ergonomics for the caregiver and the self-esteem of the person using the chair, I wanted the handle to be less conspicuous. My solution uses soft foam bicycle grips over an ergonomically comfortable oval tube placed in a natural position parallel with the chair back. (*Figure 8*)

In order to deal with the strong forces exerted on the chair when it is pushed, I attached the handle to the main aluminum structure at the back of the seat. My 'backbone' solution simply uses the four existing mounting bolts on the seat back. This has two important mechanical advantages. First, installation is easy. Second, no new holes have to be drilled which could weaken the frame. Aesthetically the backbone solution continues the centre line created by the footrest and integrates visually into the overall look of the chair. This push bar solution is the most comfortable of any wheelchair I have handled.

Wheels

A three-spoked carbon-fiber wheel manufactured in California for the sports wheelchair market would have complimented the wheelchair design. However, I couldn't justify their cost at $1,500.00 a pair and compromised with a pair of five spoked wheels at one fifth the cost. These wheels are made of plastic and have the appearance of the plastic used in the Aeron™ chair. The spaces between the spokes is large enough for an attendant to easily reach through to the tilt tension adjustment under the seat. The tires are made of polyurethane — for low maintenance and a comfortable ride. (*Figure 8*)

Summary

When Herman Miller Canada Inc. asked me what size chair they could donate to my project I assumed the middle sized B chair would suit my needs. I didn't discover my error in judgment until I had nearly completed the third prototype. I intended that this chair be used in long term care facilities for the elderly. This user group tends to be shorter and predominantly female. Hence, the smaller A chair would have been more appropriate.

I have had 6 people, who use wheelchairs now, help me evaluate my design. This testing was preliminary and was not intended to be a conclusive representation. However, it was an indication of the viability of the design. Somewhat surprisingly, none of my test subjects would sign a release to be video taped using the design. A preliminary analysis of my wheelchair design and a small sample test group indicate numerous areas for further engineering and design development:

1. The Aeron ™ chair armrests are not workable in a wheelchair application. While the vertical and horizontal adjustment is desirable, the control dials are too difficult to loosen and tighten for old and arthritic hands. The controls are confusing. To loosen the left armrest you turn the dial down, to loosen the right armrest you turn the dial up. The shape of the armrest pad is too wide at the back, it interferes with the forearms when the push rings on the chair's wheels are grasped. The armrest must be removable or at least flip out of the way for sideways transfers. The design of the Aeron ™ armrest assembly has too many parts, and could increase service costs.

2. The structural failure of the centre mounted footrest indicates this component requires serious structural analysis by an engineer. A redesign and perhaps the use of alternate materials followed by extensive testing should result in a safe footrest that meets the rigorous requirements of patient use. Adjustability both up and down and side to side would also be an improvement. The release for the footrest must be made more convenient to reach.

3. The present wheel configuration with the casters in the rear results in a very maneuverable chair. Not being able to climb curbs is not a major drawback in an indoor wheelchair.

4. Seat height adjustability would be beneficial to custom fit individual users and to assist in transfers.

5. The brake needs to be redesigned to overcome some of its limitations. Not everyone has the dexterity to reach back to operate the brake control. The present controls are not visible and brake action is not immediately understandable.

6. Any controls for adjustments can be confusing and require a learning period for the senior, therefore they must be visible, easily manipulated and functionally simple.

7. The caster track width should be increased. Some caregivers found the caster spacing too narrow and occasionally inadvertently kicked them.

8. The wheelchair push bar shape and orientation works well.

9. The visual language of the wheelchair has received very positive responses and has been judged to be 'unclinical'.

10. Off-the-shelf components can continue to be used to further refine and complete the prototype.

Conclusion

These identifiable problems with my present wheelchair prototype are not major obstacles to the continuing development of the design. In the future with more time, a suitable budget and engineering expertise, the arm rests, the foot rests, seat height adjustment, brake control and other refinements can be addressed in turn.

The aforementioned notwithstanding, I feel I have, in this project, achieved my original objective — technology transfer from the Aeron™ chair and its incorporation into an improved wheelchair design. The design embodies the unique features of the Aeron™ chair, namely the Pellicle™ seating surface and the Kinemat™ tilt system. These characteristics have demonstrable benefits for people who use wheelchairs. The initial response to my wheelchair design by professionals, lay people, wheelchair users, colleagues, and fellow students has been *enlightening* and *encouraging*. Even the able-bodied have reacted positively. I feel confident that my design, with improvements and proper project management, can be beneficial to the intended user group.

Appendix A: Methodology

Literature review

The University of Alberta Library database was searched using the keywords: "wheelchairs", "wheelchair design", "wheelchair seating", "assistive technologies", "rehabilitation", decubitus ulcers", "pressure sores", and commercial names of wheelchair manufacturers. The search was limited to the English language.

Prototype "bench" testing

Wheelchair testing standards have been developing since the Mid-1960s. The tests for all wheelchairs can be grouped in three categories: (1) static and dynamic stability tests, (2) strength tests (static, impact and fatigue) and (3) energy consumption tests.[27] ANSI, ISO, CSA, and UL standard tests were not performed on my wheelchair prototype.

I did comparative subjective tests between various standard wheelchairs and my wheelchair prototypes for static and dynamic stability. I rolled, twisted, leaned, bounced and shook the wheelchairs and prototypes noting my impressions on how they all performed. I also supervised other people comparing the stability of each wheelchair and prototype and noted that prototype III was very stable. Strength testing of the undercarriage was done by applying over 100 kg of weight and rolling over various terrains, dropping over 6" curbs and running into stationary objects. Prototype III has shown some weakness in the footrest support. Energy consumption testing was not done but everyone who used prototype III remarked on its ease of use and maneuverability.

Appendix B: Background

This wheelchair project was both ambitious and challenging. Ambitious because I had no financial sponsors and challenging because it would be difficult to meet the design integrity of the Aeron™ chair. The designers of the Aeron™ chair, Bill Stumpf and Don Chadwick, have over twenty years of furniture design experience with Herman Miller Inc. The Aeron™ chair, the team's third generation of office seating designed for Herman Miller, took two years and two million dollars to bring to market. Whatever I attempted to do with this design would be demanding.

My research included telephone contact with Herman Miller in Zeeland, Michigan. I arranged to visit Herman Miller's corporate headquarters in February 1997 before finalizing all of my project objectives. I was able to tour Herman Miller's main office, show room and a plant that assembled a variety of Herman Miller's chairs including the Ergon and Equa chairs. This proved very helpful because these two chairs directly preceded the Aeron™ chair design. I had a valuable meeting with Bill Dowell, the manager of the Aeron™ Chair project. He took me to his design lab and explained some of the processes that the team used in designing this chair. Interestingly, Herman Miller Inc. decided not to use any historical or previously published anthropometric data but started from scratch.

The design team did their own anthropometric study and designed a device to gather accurate data from seated persons. I was also able to sit in three different hand-built prototypes of the Aeron™ chair. The design team did not use any computers to design the forms within the chair. Computers were, however, used extensively for compiling data, pressure mapping, and mold making. The design of the chair was a hands-on activity: sketching, model-making, and prototyping. I took a similar approach to my design.

Upon returning to Edmonton, I had further discussions with Professor Norman Ball who contacted Mr. Chris Imler, Marketing Program Manager of Herman Miller Canada inc., about my project. I am grateful to both Dr. Ball and Mr. Imler for the gift of a fully equipped Aeron™ chair, which I have incorporated in my prototype wheelchair.

Together with addressing the prototype problems, I intend to bring my work to the attention of Herman Miller, the wheelchair research community, caregivers and wheelchair users. The properties of the Pellicle™ fabric have considerable potential and should be studied for a variety of applications, not just office seating. Car safety restraints for infants, toddlers, and pregnant women, splints, body supports, stretchers, beds, and airline seats are a few products that could be improved through the use of the Pellicle™ fabric.

Sources

Visits

University of Alberta Hospital, Edmonton, Alberta
Misericordia Community Hospital, and Health Centre, Edmonton, Alberta
Grey Nuns Community Hospital and Health Centre, Edmonton, Alberta
Strathcona Care Centre, Sherwood Park, Alberta

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Bill Melenberg, O.T., Capital Health Authority - Home care, Edmonton	March 1996
K. B. James P.Eng., Biomech Designs Ltd., Edmonton	March 1996
Nighthawk Manufacturing Inc., re. seating and positioning, Sherwood Park,	May 1996
Prof. Stuart Mcgill, Ph.D., Dept. of Kinesiology, University of Waterloo Seminar at U of A , "Integrating recent developments in lumbar mechanics,"	Sept. 1996

Internet

The following abbreviated list of Internet Sites have information pertaining to my design report These sites also have links to other wheelchair related product suppliers, support groups, and social and sports activities.

Disability Links - Mobile Devices	http://disability.com/links/mobilitydev.html
dizABLED: Disability Resources	http://www.dizabled.com/links.html
Rehabilitation Engineering Applied to Mobility and Manipulation	http://www.iop.org/Books/Catalogue/180/
The Minnesota Broken Wing Connection	http://www.uslink.net/~daryl/indoor.html
Transwheel Project Fact Sheet	http://www2.echo.lu/telematics/disabl/transwh-txt.html
Wheeled Mobility Center	http://thecity.sfsu.edu/wmc/

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26. i. Stumpf, Chadwick, and Dowell
    ii. "The Aeron ™ Chair," Herman Miller Inc., 1996 (Compact Disc)
    iii..."Aeron, Equa 2, Ergon 3, Ambi Service Procedures," Herman Miller Inc., 1996 (video)
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